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Garnet and Staurolite as potential geochronometers in low to medium grade metamorphic rocks - U/Pb and Pb/Pb garnet and staurolite ages from the Southern Damara orogen (Namibia)

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In high grade metamorphic terranes, metapelites can preserve a variety of mineral assemblages which provide quantitative estimates of metamorphic pressure and temperature. Providing quantitative estimates of the time required to develop prograde mineral assemblages is more difficult due to the fact that the closure temperatures for common isotope systems (i.e., Rb-Sr, Ar-Ar) for most minerals are lower (mostly $< 500^{o}$C) than the peak metamorphic temperatures. Dating of accessory minerals (i.e. monazite, sphene) with higher closure temperatures may be useful, however, it is still a challenge to connect the age information with metamorphic reactions that formed or modified these accessory minerals. The most ideal situation therefore, is to date prograde major rock-forming minerals that have also been used for petrographic and thermobarometric studies. Garnet and staurolith, which are important major rock-forming minerals in low/medium grade metamorphic rocks, have suitable high closure temperatures to be such minerals.

The Southern Damara orogen comprises a huge metasedimentary pile of more or less uniform chemical composition. Here, garnet and staurolith appear as a consequence of increasing pressure and temperature, forming distinct metamorphic isograds.

At the **garnet-in isograd**, garnet has high ^{206}Pb/^{204}Pb ratios up to 540 and is discordant with a lower concordia intercept of ca. 400 Ma. The upper concordia intercept gives an U-Pb age of ca. 780 Ma, similar to intrusion ages of rift-related syenites from the northern part of the orogen. A Rb-Sr whole rock isochron of the country rock metapelites gives an age of c. 770 Ma. These results indicate that the garnet most likely contains an inherited accessory component that was derived from rift-related igneous rocks and was subsequently incorporated into the garnet. The ill-defined lower

intercept of c. 400 Ma reflects the growth of garnet close to the inferred second metamorphic peak which occurred at c. 480-460 Ma (see below).

At the **staurolite-in isograd**, garnet has lower $^{206}Pb/^{204}Pb$ ratios up to 130 and define two populations. These populatios are syn-tectonic garnet with an age of c. 550 Ma and post-tectonic garnet with an age of c. 480 Ma. Staurolith has very low $^{206}Pb/^{204}Pb$ ratios of < 20 and defines also two populations (syn-tectonic/post-tectonic). In a Pb-Pb isochron diagram, the syn-tectonic staurolite fraction plot on the isochron defined by the garnet fractions from the same sample with an apparent age of c. 550 Ma. Similarly, the post-tectonic staurolite fractions plot on the isochron defined by the post-tectonic garnets with an apparent age of c. 460 Ma.

At the **kyanite-in isograd,** garnet has low $^{206}Pb/^{204}Pb$ ratios up to 50 in which syn-tectonic garnet has an apparent age of c. 540 Ma and post-tectonic garnet and staurolite record ages of c. 460 Ma, again implying growth of garnet and staurolite at two distinct episodes of medium-grade regional metamorphism.

At **the andalusite-sillimanite isograd**, weakly reverse discordant garnet has a lower concordia intercept of c. 480 Ma. These garnet fractions together with the staurolite fractions from the same sample define a Pb-Pb age of c. 460 Ma, again confirming the growth of garnet and staurolite relatively late in the metamorphic history.

From these data, it is evident that the Southern Damara orogen underwent a two-phase regional metamorphic history in which each metamorphic peak obviously involves thickening and heating of the crustal segment. Based on the large time interval of c. 70 Ma it is unlikely that both metamorphic ages correspond to the same metamorphic event. The preservation of ancient staurolith ages with similar ages than the corresponding garnet (with their high Tc of $> 800^oC$ for Pb) implies that the closure temperature of U-Pb in staurolite is, at least similar or higher than 550^oC which is the maximum temperature recorded by conventional thermobarometry. Available Rb-Sr and Ar-Ar muscovite and biotite ages range from c. 450 Ma to c. 480 Ma roughly similar to the Pb-Pb staurolite ages that corresponds to the second regional metamorphic event. This similarity implies rapid cooling rates at the end of the Pan African metamorphic event in this area.